Upper Ottawa Landfill Leachate:
Treatment Feasibility Study

By

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Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction

Boojum Research Ltd was approached by C. Murdoch and J. Readman of the Solid Waste Management Division, Public Works Department, City of Hamilton, to help develop design criteria for a passive treatment system for leachate originating in the Upper Ottawa Landfill.

A site visit was carried out by Martin Smith, a professor at Niagara College (Ecosystem Restoration Program) and Margarete Kalin on 24th of November 2003. Leachate samples were collected during the site visit and on December 22nd. Testing of the leachate samples took place at the Boojum Research Ltd. Laboratory to define key parameters for the design of the pilot test system.

1.1 Objective of the Feasibility Tests

Natural treatment systems for waste water are dominated by several processes:

- aerobic – the chemical and microbial oxidation of reduced inorganic and organic compounds.
- anaerobic – the microbial degradation and utilization of contaminants in oxygen-free, low redox conditions.
- adsorption of contaminants onto both abiotic and biotic particulates.
- uptake of contaminants by zooplankton, lower and higher plants.

The feasibility test, conducted in the Boojum laboratory, simulated the first two processes at room temperature to reflect summer conditions. This will be adjusted to winter conditions according to the general known Q10 which represents the metabolic rate of microbial activity. It indicates a reduction in microbial processes by a factor of about 2 for every 10°C reduction in temperature. Small rocks were submerged in the samples to provide anchorage for microbial bio-films. Algae, tolerant to alkaline conditions, were added to assess the phyto-toxicity of the leachate.

2. Materials and Methods

2.1. Field sampling

Leachate samples were collected from a manhole at the Upper Ottawa Landfill Site on Nov. 24th (15 L) and Dec. 22nd (40 L) 2003 using a pail suspended from a rope. The samples were brought to Boojum's lab in Toronto in plastic buckets lined with a new sterile plastic bag. Table 1 (below) summarizes the pH, conductivity, redox potential, temperature and dissolved oxygen (O_2) of the samples as determined in the field. The oxygen meter was not available during the first sampling campaign.

Table 1: Sample Field Measurement Data

Leachate	pH	Cond, uS/cm	Em, mV	T, ^oC	O_2, mg/L
First sample collected on Nov. 24/03	7.89	4110	280	10.1	-
Second sample collected on Dec. 22/03	7.85	4710	328	11	6.48

2.2 Experimental Design

2.2.1: First sampling tests

On December 2, the first sample was divided into three equal (5 L) sub-samples contained in 5.5 L plastic containers. One of the sub-samples served as a control, the second was aerated with an aquarium pump and the third was filled with 3 cm diameter granitic rocks. The third sample was aerated and circulated from the bottom by a centrifugal pump at the rate of 80 ml/min. The rocks provided a void ratio of 0.45 in the container or 15 ml per rock. This provided a surface area of about 0.5 m in the aquarium.

The pump was turned off during night hours to prevent over-heating of the leachate. Six days after set up, the third sub-sample (aerated and circulated sample with rocks) spilled, requiring the addition of control water to replenish the treatment; it is assumed that this did not affect the development of an aerobic bio-film on the rocks.

On the tenth day following the start of the treatment, 300 ml of leachate were sampled from each container and sent to Saskatchewan Research Council (SRC) for analysis of organic and inorganic constituents, ICP-25, Sulfur, Nitrite and Nitrate as Nitrogen, Ammonia as Nitrogen, Total Kjeldahl Nitrogen (TKN) as Nitrogen, Total Organic Carbon (TOC), Inorganic Carbon, Biochemical Oxygen Demand (BOD), Chloride and Potassium analyses. Chemical Oxygen Demand (COD) was also determined.

On December 12, 17.8 g of wet weight algal biomass were added to the two treatments (sub samples 2 and 3). The algal culture consisted of *Spirogyra* spp., *Cladophera* spp. and *Chara vulgaris* which are cultivated in an aquarium in the Boojum laboratory. The algal biomass was determined by blotting the biomass three times before weighing. Through repeated weighing over time the growth or decay of the algae can be determined. If the algae do not lose biomass it is assumed that the growing medium, or leachate samples, are not phyto-toxic. The biomass (36.8g) from both treatments was transferred into one aquarium containing the rocks with the presumed bio-film and aerated. New rocks of the same size were added to the aquarium with old leachate and were not aerated until after sampling on December 30th 2003. This was to allow the development of an anaerobic bio-film. Both aquaria from the first experiment were sampled on December 29th 2003 for further analysis of the same parameters as before. Table 2 (below) presents the history of the first set of samples.

Table 2: History of First Set of Samples

Treatment	System setup date	Active treatment days	Storage to analysis days
Control	2-Dec-03	-	3
Aerated	2-Dec-03	10	3
		21	13
		27	7
Aerated, circulated, old rocks	2-Dec-03	10	3
		21	13
		27	7
Aerated + new rocks	23-Dec-03	6	7

2.2.2: Second sampling tests

The second sample was set up on December 22. It was divided into four 5 L sub-samples. One of these served as a control, one was aerated with rocks, one aerated without rocks, and one was with rocks with intermittent circulation. The rocks were the same size as in the first experiment. After 7 days the leachate from all containers and the aquaria from the first experiment were sampled and the samples stored in the refrigerator at 7^{o} C until shipment, on the advice of the supervisor from SRC, since they would not be analyzed until January 5, 2004. The experimental containers and the aquaria were covered with a light plastic lid to reduce evaporation. The experimental set-up is shown in Figure 1.

The pH, conductivity, redox potential, temperature and dissolved oxygen for all the treatments were determined daily and all the samples were titrated on the 29th of December 2003. The history of the second set of samples is given in Table 3.

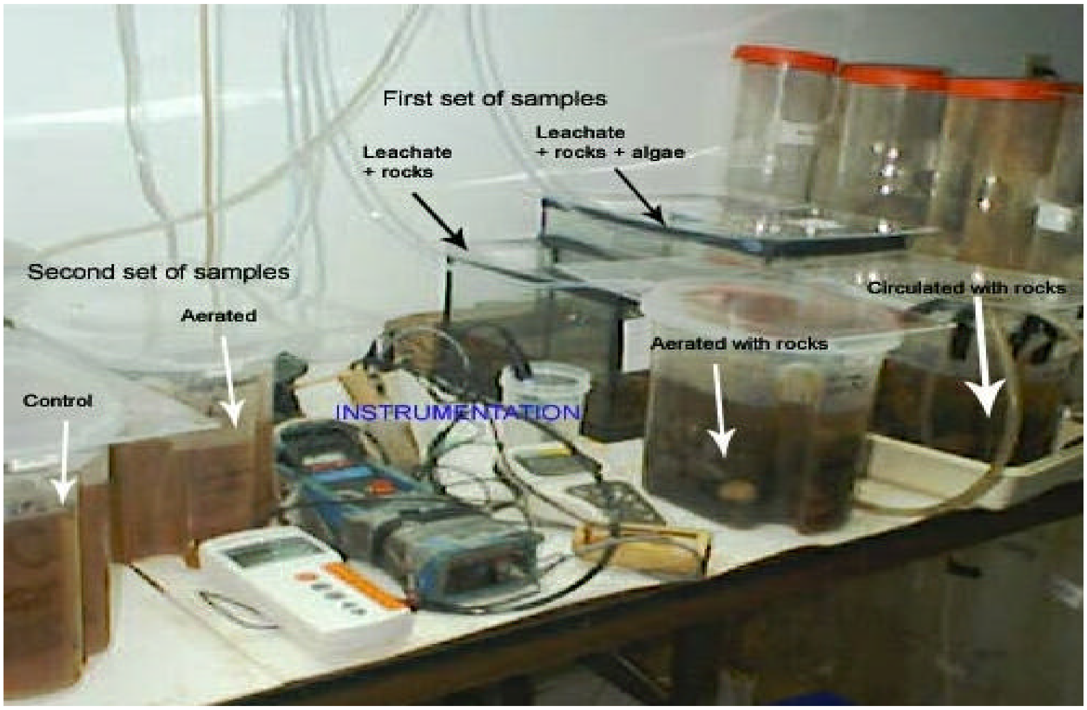


Figure 1: Experimental Setup

Table 3: History of Second Set of Samples

Treatment	System setup date	Active treatment days	Storage to analysis days
Control	22-Dec-03	-	13
		-	9
		-	7
Aerated	22-Dec-03	2	12
		5	9
		7	7
Aerated with Rocks	23-Dec-03	1	12
		4	9
		6	7
Circulated with Rocks	23-Dec-03	1	12
		4	9
		6	7

2.3 Instrumentation

A Corning 315 pH/Ion pH meter equipped with a combination electrode, also by Corning (#33221 -034), was used after the pH probe was calibrated with buffers at pH 4 and 7 prior to each run of the pH determination. The conductivity measurements were performed using an OAKTON Con 400 series EC instrument set to mS or µS mode and temperature was recorded. The instrument adjusts the reading to 25^{o}C automatically. A Corning M103 redox instrument with an inert platinum electrode and a standard Calomel probe was used to determine the measured redox potential (Em). Em was converted to standard redox potential at 25^{o}C (Eh) by using the following formula:

$$Eh = Em + (241-(0.66*(\text{Sample Temperature in } ^{o}C - 25)))$$

Oxygen Sensor (model YSKI5795) connected to a Dissolved Oxygen Meter (YSI model 58) was used to measure oxygen dissolved in the leachate samples which were bubbled and circulated by OPTIMA air and IWAKI centrifugal pumps respectively. The oxygen sensor was calibrated daily according to ambient temperature and elevation. A SAUTER top loading balance, with a precision of 0.01 g, was used to weigh algae. Acidity and alkalinity of the samples were determined using a 702 SM Titrino (Brinkmann; Metrohm).

3. Results

It is accepted that the water quality of landfill leachate varies. Table 4 indicates existing water quality parameters as well as contaminants detected from August 1999 to October 2003 in leachate samples from the Upper Ottawa Landfill. Lowest and highest values are provided and are compared to both Sewer Use Discharge Criteria and to Provincial Water Quality Objectives.

The maximum concentration of contaminants detected in the leachate exceeds Sewer Use Discharge Criteria for TKN, TSS, iron and mercury (Dissolved). Data provided by the City of Hamilton's Regional Environmental Laboratory were examined for seasonal trends of highs and lows, but none were detected. Therefore it is not possible to conclude as to whether or not the samples used in the Boojum tests were representative of the leachate. The first sample collected on November 25th seems to fall in the medium range for TSS (11.2 mg/L) and for TKN (139 mg/L), but in the low range for Fe and Hg values. For the second sample, collected on December 22nd, TSS and Hg were not determined. The value of TKN concentrations (preliminary) was 173 mg/L and iron was 0.2 mg/l. Since it is not expected that TSS would be difficult to remove with a passive treatment system and Hg values are generally low, the primary objective of the proposed passive pilot system will be to reduce TKN and Iron.

Mulamoottil, McBean and Rovers writing in “Constructed Wetlands for the Treatment of Landfill Leachate“ (CRC Press 1999) attempt to classify leachate characteristics by age. The Upper Ottawa Landfill leachate (Site closed 24 years ago) falls into none of the categories enumerated by the authors. The values summarized from the existing monitoring data (Table 4) fall into all ranges of values given. It is therefore assumed that the characteristics of the leachate will remain constant for a considerable period of time. A pilot test system using passive treatment is recommended to address the sewer use discharge criteria and the degradation of the recalcitrant chemicals which likely contribute to high COD values.

Table 4: Manhole leachate historical chemical parameters (units: mg/L unless specified). Maxima in bold exceed Sewage Discharge Criteria.

Analyte	Sewer Discharge Criteria	Provincial Water Quality Objectives	Minimum From	Maximum To
			6-Aug-99	6-Oct-03
Total Kjeldahl Nitrogen as N	=100		15.5	**314**
Total Suspended Solids	=350		<1.5	**1880**
Iron	=50	0.3	1.3	**82.5**
Mercury-Dissolved ug/L	=0.1	0.2	<0.1	0.2
Cyanide - Total	=2	0.005	0.011	0.03
Phenols mg/L	=1	0.001	<0.003	0.15
Phosphorus Total	=10	0.01	0.536	3.5
Boron		0.2	1.89	16.4
Cadmium	=1	0.0002	<0.0006	0.0011
Cobalt	=5	0.0009	0.0078	0.0358
Copper	=3	0.005	0.007	0.206
Lead	=5	0.003	0.002	0.3
Nickel	=3	0.025	0.039	0.111
Silver	=5	0.0001	<0.002	<0.005
Thallium		0.0003	<0.1	<0.11
Vanadium	=5	0.006	<0.005	0.123
Zinc	=3	0.02	0.05	2

Although the primary objective is to achieve sewer use discharge criteria, a secondary objective will be to achieve Provincial Water Quality Objectives (PWQO), clearly a high goal. These objectives need to be achieved through microbial and algal treatments. A brief assessment of other potentially toxic substances needs to be made but it need not include substances at or below the analytical detection limits given for sample 1 and 2 in Table 5.

Table 5: Elements at or below the Analytical Detection Limits (mg/L)

Analyte	Al	Be	Cd	Pb	Ag
Sample 1	-	< 0.005	< 0.001	< 0.002	< 0.002
Sample 2	< 0.005	< 0.001	< 0.001	< 0.002	< 0.002

It might be expected that biological oxygen demand and chemical oxygen demand reflect the potential treatability of the leachate with biological systems. In Table 6 these parameters are summarized for the monitoring data from the manhole of the Upper Ottawa leachate collection system. They display a relatively constant ratio of BOD to COD suggesting that about one tenth of the oxygen in the leachate is utilized by microbial activity and the remainder by presently unidentified substances which likely belong to the recalcitrant group of contaminants.

Table 6: BOD, COD and TOC

Analyte	06-Aug-99	30-May-00	15-Sep-00	8-Jun-01	21-Jun-02	21-Nov-02	23-Apr-03	6-Oct-03
BOD	77	38	45	38	55	18	23	73
COD	996	524	694	601	340	295	309	776
TOC	195	150	157	141	132	18.3	90.1	180
BOD/COD	0.077	0.073	0.065	0.063	0.162	0.061	0.074	0.094

Relationships between the three parameters have long been suspected. B. Stanek, (personal communication) the head of analytical services of the Saskatchewan Research Council, observed that nothing has changed in the field since the short publication in 1976 found in Journal of Water Pollution Control Federation Vol. 48, No 9 pp 2213 to 2214, by Viragaghavan. He concluded that there is no significant relationship between these parameters if samples from raw sewage, septic tank and polluted ground water are compared. Stanek confirmed that this is also the case for landfill leachate. However for the Upper Ottawa landfill leachate it appears that the ratios among these parameters are relatively consistent. As much of the TOC is likely a component of TSS, it is likely that it will be reduced in a passive treatment system.

The first test run represented aeration and circulation, supplemented with rocks. It was set up with the assumption that if a flow of 12 L/minute was to be treated then the maximum retention time for the pilot test system would be about seven days, given the considerations laid out in Table 7. The temperature differences in the field between winter and summer months would be expected to be at least two Q10 values.

Table 7: Pilot Wetland Residence Time Calculations

Gravel Depth, m	pore volume / m^2	Wetland Area (ha)				
		0.005	0.0075	0.05	0.5	1
		Residence Time (days)				
0.5	0.25	*0.7*	*1.1*	*7.2*	*72.3*	*144.7*
1	0.5	*1.4*	*2.2*	*14.5*	*144.7*	*289.4*

Flow Volume = 0.0002 $m^3\ s^{-1}$ Flow Volume = 12L/minute

A gravel bed depth of about 0.5 m for bio-film formation and a total area of about 0.05 ha for the pilot test system seem reasonable. Of course, these parameters can be manipulated in many ways but they served as a general guideline for testing the feasibility of the system. However, If no reductions in leachate contaminants to Sewer Use Discharge Criteria can be obtained by the ideal conditions in the laboratory then a pilot for a passive treatment system would not be appropriate.

From the values of TKN after 10 days of set up it is evident that ammonia and TKN have been reduced while nitrate increased and some of the parameters appear to have been converted to organic carbon. Reductions are also noted in inorganic carbon and BOD (Table 8).

Table 8: Results for Sample Set 1 (mg/L)

Analyte	Stagnant / Control	Aerated		Aerated + new rocks no algae	Circulated with rocks		Circulated Aerated + old rocks + algae
	12-Dec-03	12-Dec-03	23-Dec-03	Dec-29-03	12-Dec-03	23-Dec-03	29-Dec-03
Alkalinity	1750	1480	-	-	1400	-	-
Ammonia as N	98	37	0.4	0.03	0.54	0.18	0.15
Barium	0.037	0.015	0.02	0.045	0.076	0.049	0.024
Bicarbonate	1910	1460	-	-	1540	-	-
BOD	43	37	3	4	1	6	2
Boron	11.2	11.3	12.6	17.7	13.7	15.7	13
Carbonate	113	169	-	-	82	-	-
COD	320	359	320	412	432	464	280
Chloride	840	775	882	1320	965	1340	920
Chromium	0.021	0.02	0.021	0.024	0.023	0.021	0.02
Cobalt	0.01	0.008	0.011	0.029	0.021	0.023	0.011
Copper	0.035	0.025	0.027	0.088	0.082	0.068	0.038
Inorganic Carbon	398	321	256	291	319	290	181
Iron	0.26	0.13	0.029	0.027	0.09	0.03	0.014
Manganese	0.021	0.007	0.002	0.014	0.089	0.022	0.004
Molybdenum	0.01	0.008	0.012	0.015	0.013	0.013	0.009
Nickel	0.059	0.044	0.053	0.079	0.059	0.064	0.054
Nitrate + Nitrite as N	9.4	1.9	103	33	92	32	112
Organic Carbon	90	57	150	110	124	140	58
Phosphorus	0.39	0.29	0.19	1.4	1.1	0.76	0.42
Potassium	-	-	250	310	-	330	260
Silicon, soluble	15.3	15.2	16.8	16.2	17.2	15.4	15.5
Strontium	1.38	0.99	0.92	1.27	1.8	1.24	0.8
Sulphur	44	44	60	97	73	83	55
TKN	93	38	7.6	20	10	13	12
Titanium	0.005	0.005	0.001	<0.001	0.002	<0.001	<0.001
Vanadium	0.01	0.01	0.01	0.018	0.012	0.014	0.012
Zinc	0.023	0.018	0.021	0.22	0.04	0.22	0.1
Zirconium	0.011	0.01	0.009	0.004	0.008	0.007	0.004

In the first 10 ten days, sample 1 ammonia concentrations decreased by 62 % (control) to 99 % (circulated with rocks; Table 9). BOD removal was enhanced in the circulated with rocks treatment where 98 % was removed in the first ten days, compared to only 14 % in the control. TKN removal in the circulated with rocks treatment (89%) also exceeded the control (59 %) in the first 10 days.

Table 9: Reduction in organic composition for sample 1

Organic composition	Amonia as N	BOD	Inorganic Carbon	Organic Carbon	TKN
Stagnant / Control					
Final after 10 days mg/L	98	43	398	90	93
Aerated					
Final after 10 days mg/L	37	37	321	57	38
Reduction mg/L/day	6.1	0.6	7.7	3.3	5.5
% reduction	62	14	19	37	59
Final after 21 days mg/L	0.4	3	256	150	7.6
Reduction mg/L/day	4.6	1.9	6.8	NC	4.1
% reduction	100	93	36	NC	92
Aerated + new rocks and no algae					
Final after 27 days mg/L	0.03	4	291	110	20
Reduction mg/L/day	3.6	1.4	4.0	NC	2.7
% reduction	100	91	27	NC	78
Circulated with rocks					
Final after 10 days mg/L	0.54	1	319	124	10
Reduction mg/L/day	9.7	4.2	7.9	NC	8.3
% reduction	99	98	20	NC	89
Final after 21 days mg/L	0.18	6	290	140	13
Reduction mg/L/day	4.7	1.8	5.1	NC	3.8
% reduction	100	86	27	NC	86
Circulated, aerated + old rocks + algae					
Final after 27 days mg/L	0.15	2	181	58	12
Reduction mg/L/day	3.6	1.5	8.0	1.2	3.0
% reduction	100	95	55	36	87

The laboratory test confirmed that leachate can be improved through natural oxidation.

The next questions were:

1) Could the leachate be aerated to maintain aerobic conditions?

2) Does the chemical oxygen demand utilize all of the oxygen immediately?

3) Could a reduction in the same parameters be achieved in a shorter time span?

To answer the first question, the oxygen concentration was determined with an oxygen meter in the presence of regular aquarium aeration stones. In Figure 2 the increase in oxygen concentration is given (open circles) for the leachate which was allowed to stand for about 24 h after aeration. At time 0 (24 hours after cessation of aeration) the oxygen concentration had dropped to 4 mg/L and it took approximately 100 minutes for the leachate to reach near saturation without the addition of oxygen. The closed circles in Figure 2 represent the control sample which was never aerated. Aeration began at time 0 (oxygen concentration below 1 mg/L) and the oxygen concentration was measured at regular intervals. The data suggest that within 60 minutes the oxygen concentrations can reach near saturation. The saturation value lies between 7 and 8 mg/L (typical oxygen concentrations in water at this temperature and elevation). It does suggest that aeration through waterfalls or water wheels should produce rapid increases in oxygen concentration.

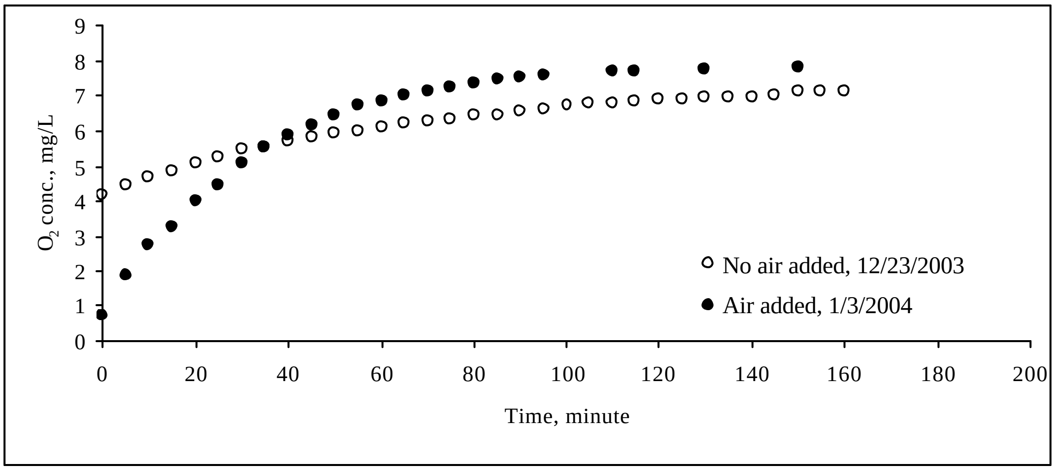


Figure 2: Oxygen Uptake by Leachate Samples

In Figure 3 it can be seen that aeration with circulation results in saturated conditions within 10 minutes of adding oxygen. Additionally, the decrease of oxygen was monitored once aeration stopped. This curve suggests that the consumption of oxygen, likely by the chemical oxygen demand, is very slow. Therefore it can be deduced that the oxygen consumption by the leachate is a slow process.

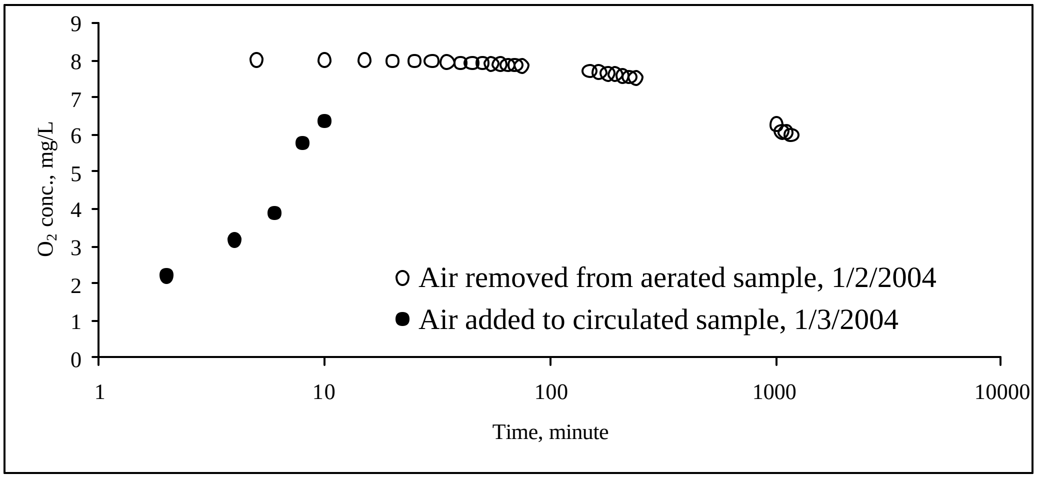


Figure 3: Oxygen Removal (likely by COD)

Figure 4 reflects the oxygen monitoring of the second sample tested under similar conditions. However, the effects of each type of treatment have been separated out with respect to oxygen concentrations in the leachate.

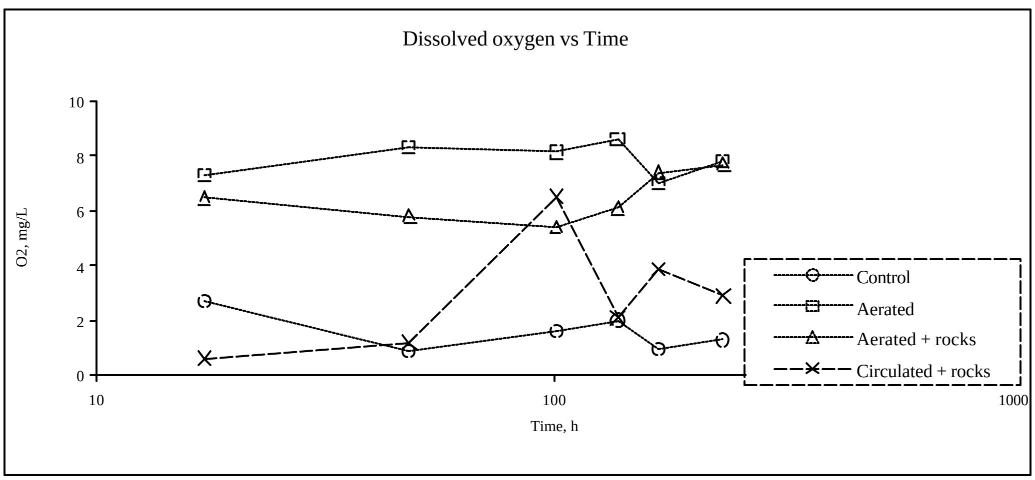


Figure 4: Oxygen Levels in Circulated Samples

Generally, continuous aeration with the aquarium pump maintained saturation levels of oxygen. Through the introduction of rocks with bio-films it was found that some of the oxygen was consumed. Additionally, the oxygen consumption in the treatment of intermittent circulation (pump was shut off over night) showed that the lowest oxygen concentration was maintained, close to the control, which was stagnant.

Figures 5 and 6 document the monitoring data during the experiment of the first sample set for conductivity and pH. Except for the last measurement (possibly erroneous) the conductivity did not change significantly. The pH values increased initially only to drop again in the aerated and circulated sample.

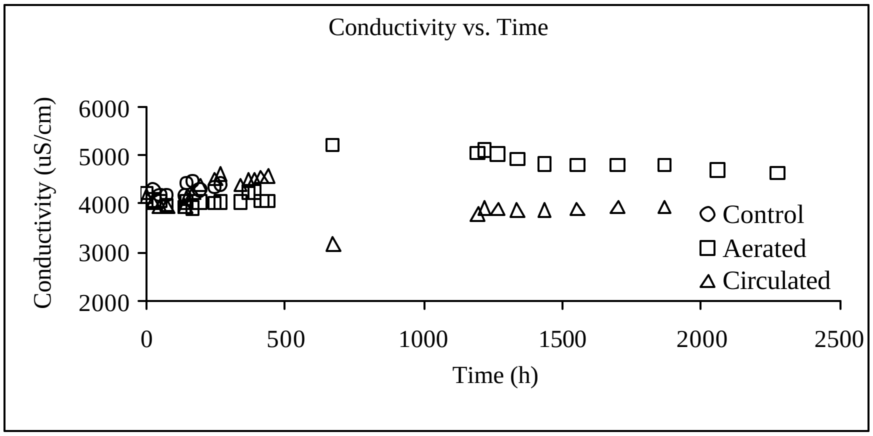


Figure 5: Conductivity vs. Time (Sample Set 1)

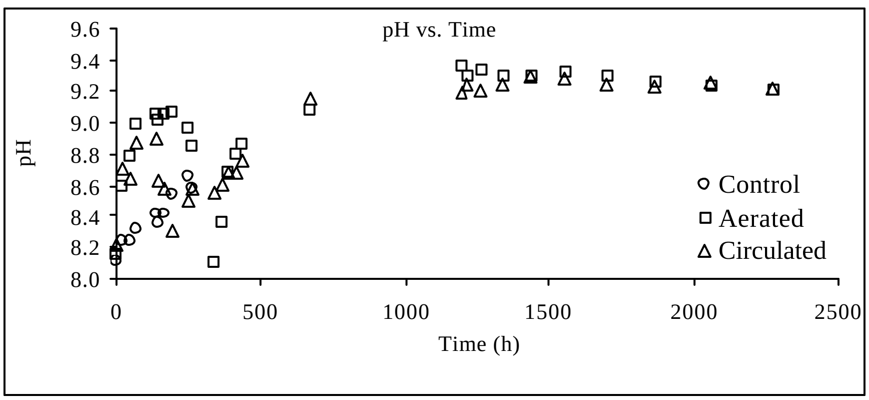


Figure 6: pH vs. Time (Sample Set 1)

In Figures 7 and 8 the same values are reported for the second sample set. The same trends can be observed (on log scale).

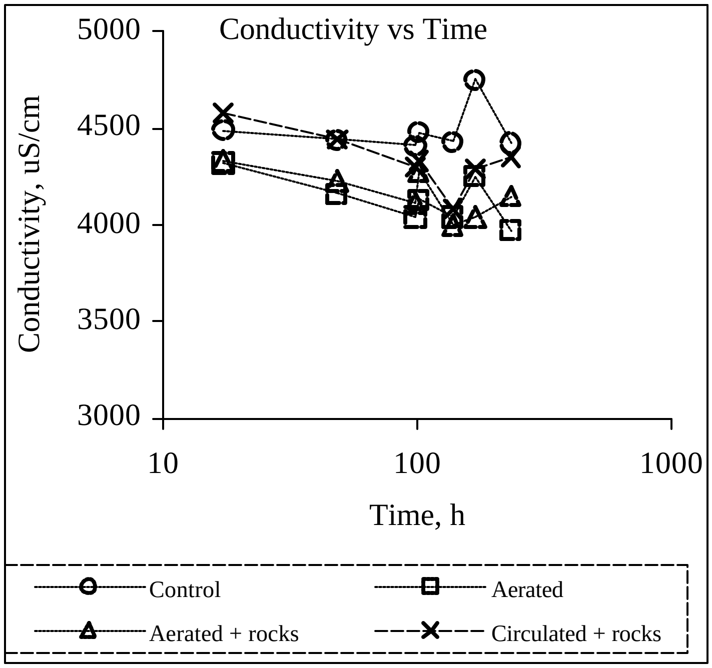


Figure 7: Concentration vs. Time (Sample Set 2)

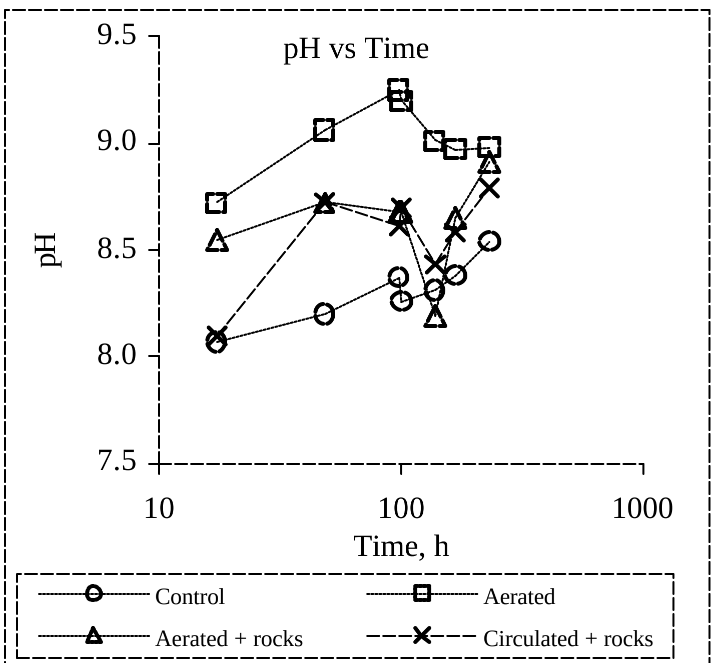
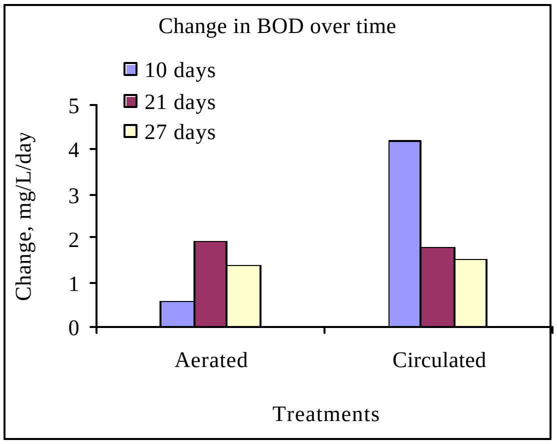


Figure 8: pH vs. Time (Sample Set 2)

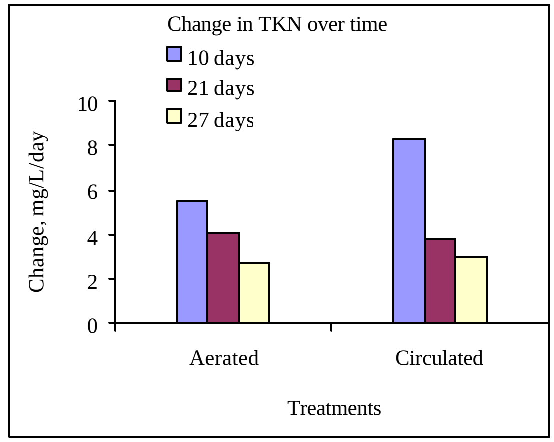
In Table 10 the results are presented from the analysis of the second sample that was set up one day after sampling from the manhole. The values after the first round of analysis were very low and required repetition to assure certainty. Generally the trends from the relevant values appear to be the same as in the first sample set, most notably the decreases in BOD, TKN and ammonia in the three aerated and circulated treatments.

Once this analysis was obtained, the remaining leachate from the second sample was combined to be cultured together with algae and rocks in the Boojum laboratory. This was implemented, since the data from the first sample set, presented in Table 8, indicated that the aquaria in which the first sample set leachate was kept (with algae and rocks) showed a tendency for the reduction of some of the PWQO-related parameters, such as Fe. Although the reduction was minimal, the amount of algae in the tanks was small.

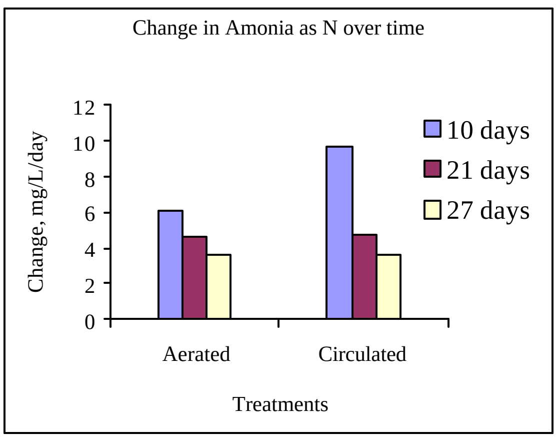
Figures 9a-d show a decreasing trend over time in the composition of BOD (9a), TKN (9b), ammonia as N (9c) and inorganic carbon (9d) caused by aeration and circulation treatments. The later treatment characteristically increased removal rates except in case of inorganic carbon.



9a



9b



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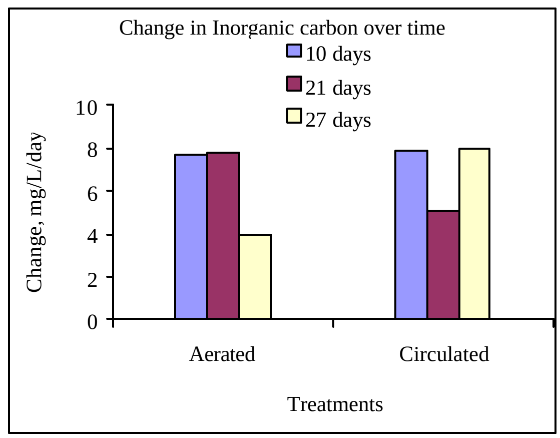


9d

Figure 9a-d: Histograms of first set of samples

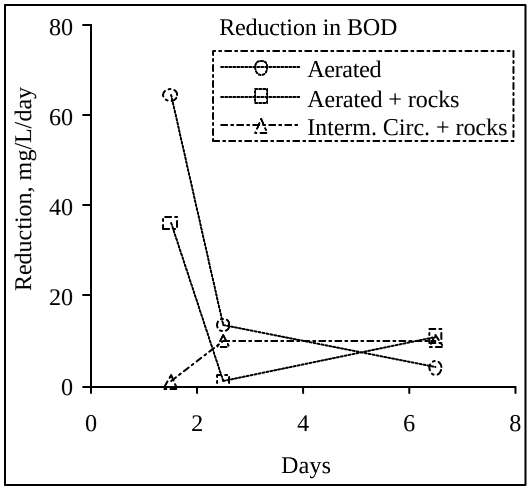
Table 10: Results for Sample Set 2 (mg/L)

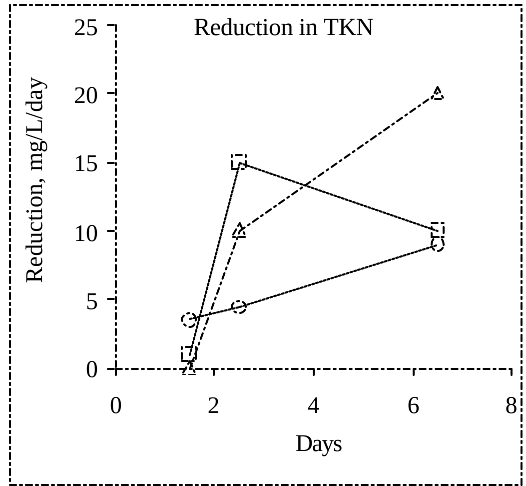
Analyte	Control / Stagnant			Aerated			Aerated with rocks			Circulated with rocks		
	Dec-23-2003	Dec-27-2003	Dec-29-2003	Dec-24-2003	Dec-27-2003	Dec-29-2003	Dec-24-2003	Dec-27-2003	Dec-29-2003	Dec-24-2003	Dec-27-2003	Dec-29-2003
Elements in Provincial Water Quality Objectives												
Decrease												
Titanium	0.006	0.004	0.006	0.006	0.005	0.004	0.005	0.002	0.002	0.005	0.004	0.002
TKN	173	166	150	166	144	89	178	105	90	173	126	30
Increase												
Copper	0.017	0.012	0.023	0.021	0.021	0.024	0.033	0.026	0.039	0.027	0.018	0.062
Phosphorous	0.39	0.31	0.43	0.4	0.38	0.41	0.72	0.81	1	1.1	1.2	0.65
Zinc	0.019	0.011	0.02	0.19	0.011	0.016	0.19	0.15	0.31	0.34	0.31	0.27
No change												
Boron	10.8	8.4	12.5	11.4	11.8	12.5	11.1	8.3	11.9	11.6	11.6	13.3
Cobalt	0.007	0.006	0.009	0.008	0.009	0.009	0.009	0.008	0.016	0.011	0.016	0.02
Iron	0.2	0.12	0.19	0.13	0.09	0.10	0.16	0.074	0.094	0.24	0.14	0.075
Nickel	0.041	0.03	0.05	0.043	0.044	0.049	0.043	0.03	0.046	0.044	0.046	0.052
Vanadium	0.009	0.006	0.01	0.009	0.011	0.011	0.009	0.006	0.009	0.009	0.008	0.011
Zirconium	0.007	0.007	0.007	0.006	0.006	0.005	0.006	0.004	0.004	0.007	0.008	0.005
Elements NOT in Provincial Water Quality Objectives												
Decrease												
Ammonia as N	134	147	155	147	118	78	146	90	12	159	127	24
BOD	187	106	77	58	39	49	151	132	12	228	66	16
Chloride	755	407	499	254	760	752	410	620	415	412	780	280
Inorganic C	273	279	348	290	201	312	275	169	204	370	460	217
Organic C	98	79	88	78	54	100	65	28	58	130	56	41
Increase												
Manganese	0.008	0.023	0.019	0.003	<0.001	0.001	0.11	0.045	0.12	0.27	0.25	0.21
Nitrite+Nitrate	9.3	8.4	8.2	9.4	13	27	10	44	140	6.1	0.06	91
Strontium	1.23	1.15	1.6	0.9	0.81	0.87	0.9	0.94	1.33	1.9	1.81	1.91
Sulfur	30	23	36	32	34	36	32	23	35	34	35	40
No change												
Barium	0.031	0.052	0.057	0.029	0.012	0.013	0.089	0.05	0.063	0.14	0.1	0.096
Chromium	0.024	0.015	0.024	0.021	0.022	0.023	0.021	0.015	0.021	0.023	0.021	0.022
COD	332	280	296	280	296	320	332	332	436	308	280	384
Molybdenum	0.008	0.005	0.004	0.004	0.005	0.005	0.003	0.002	0.005	0.003	0.004	0.006
Potassium	200	210	250	230	230	230	220	180	230	220	210	250
Silicon	14.1	10.1	16	13.3	14.2	16	12.5	12.4	13.9	14.6	15	14.9

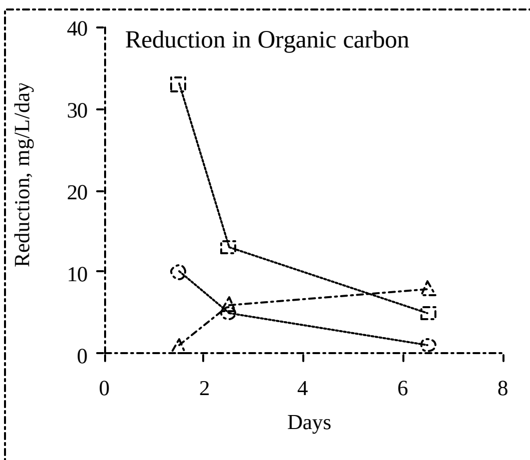
Table 11: Reduction in organic composition for sample 2

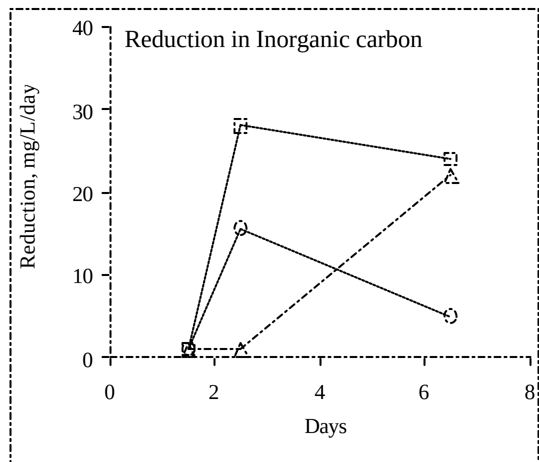
Analyte	Control / Stagnant	Aerated			Aerated with rocks			Intermetantly circulated with rocks		
	Final mg/L	Final mg/L	Reduction mg/L/day	% reduction	Final mg/L	Reduction mg/L/day	% reduction	Final mg/L	Reduction mg/L/day	% reduction
Final after 1-2 days										
N- Ammonia	134	147	NC	NC	146	NC	NC	159	NC	NC
BOD	187	58	64.5	69	151	36	19	228	NC	NC
Inorg. Carbon	273	290	NC	NC	275	NC	NC	370	NC	NC
Org. Carbon	98	78	10	20	65	33	34	130	NC	NC
TKN	173	166	3.5	4	178	NC	NC	173	0	0.0
Final after 4-5 days										
N- Ammonia	147	118	5.8	20	90	14	39	127	5	14
BOD	106	39	13.4	63	132	NC	NC	66	10	38
Inorg. Carbon	279	201	15.6	28	169	28	39	460	NC	NC
Org. Carbon	79	54	5	32	28	13	65	56	6	29
TKN	166	144	4.4	13	105	15	37	126	10	24
Final after 6-7 days										
N- Ammonia	155	78	11	50	12	24	92	24	22	85
BOD	77	49	4	36	12	11	84	16	10	79
Inorg. Carbon	348	312	5	10	204	24	41	217	22	38
Org. Carbon	88	100	NC	NC	58	5	34	41	8	53
TKN	150	89	9	41	90	10	40	30	20	80

An increased reduction over time in the five analytes, BOD, TKN, organic carbon, inorganic carbon and N-ammonia reported in Table 11 can be noticed in Figure 10. The treatments had significant effect during first two days of operation after which the effect was not regular.









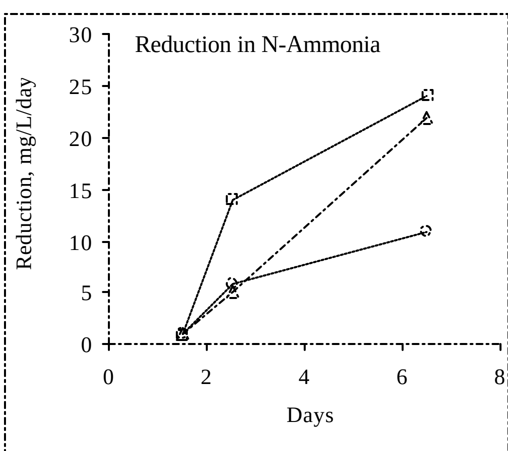


Figure 10: Reduction in organic composition of BOD, TKN, organic carbon, inorganic carbon and Ammonia as N.

Figure 11 titration curves for both sample sets (1 and 2) are shown along with the treatments, including sample 1 aquarium where algae was added. The shape of the curve suggests clear changes in composition of the sample. Generally the data suggest that the passive system will have a reasonable potential to remove contaminants, but many organic parameters need to be tested in more detail.

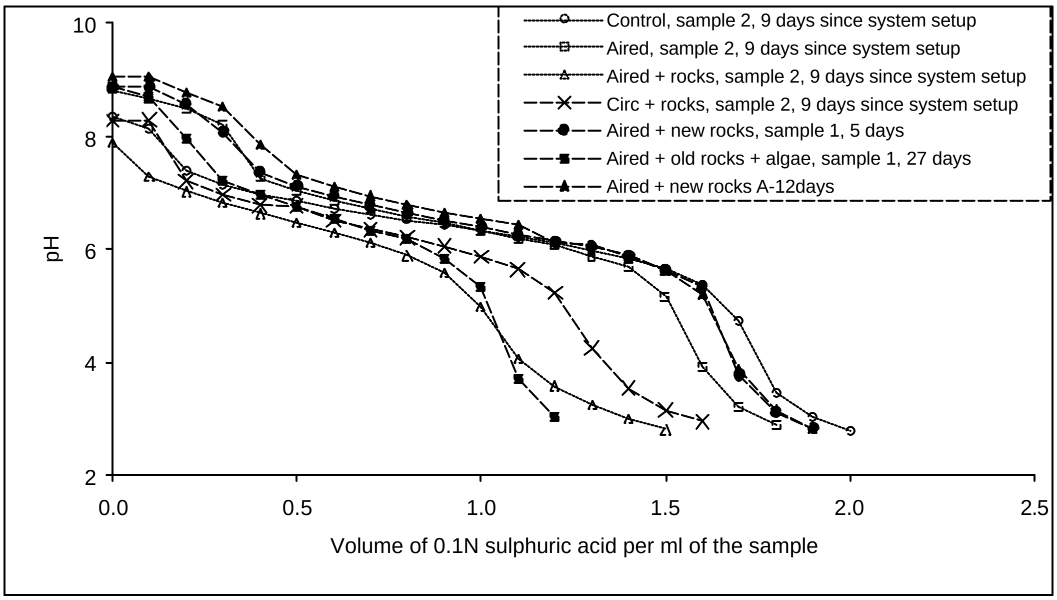


Figure 11: Titration Curves for Sample Sets 1 and 2

4. Conclusions

It is presumed the pilot wetland treatment system will be set up on top of the landfill where leachate will be pumped up from the manhole and drawn by gravity through the system. The possibility of re-circulating the treated leachate and mixing it with raw leachate or a complete second feed through the passive treatment system could be considered since the circulated test showed interesting results (possibly due to the pulsing of oxygen into the leachate).

The pilot system should be constructed so that it will be possible to adjust the sequence of treatment steps, alternating aerobic to anaerobic. An engineering firm should be able to create a container system which could accommodate the following criteria.

1) 3 to 4 Ponds, covering about 0.05 hectares with aeration through water falls or water wheels which would provide about 7 days residence time. The ponds would contain gravel, similar in size to the gravel used in the experiments to allow for the development of bio-films under both aerobic and anaerobic conditions.
2) No pipes but open flow channels connecting the treatment cells. (Pipes clog up and develop their own bio-film, producing maintenance problems.)
3) Buoyant vegetation islands, floating in a depth of at least 1 metre of water, changing between aerobic and anaerobic systems. Those will be arranged on the gravel beds or the aeration ponds as possible. These floating islands will facilitate the breakdown of substances which lead to COD. At present these processes are not fully understood but it seems likely they are driven by aerobic and anaerobic bacteria in the floating root zone. A literature review study should reveal more about the processes, as the degradation of many of the unknown organic substances contained in landfill leachate are determined in the laboratory.
4) Generally the system should be kept as simple and as self sustaining as possible. Some mechanical devices will be required, to flush, aerate or conceivably heat the treatment system, but these should be kept to a minimum.

5. References

Mulamootil et al., (Eds.)1999. Constructed Wetlands for the Treatment of Landfill Leachates.CRC Press.

Viragaghavan, J. 1976. Correlation of BOD, COD and soluble organic carbon. Wat. Poll. Cont. Fed. V 48 (9);2213-2214.

Other relevant reading

Steinmann, C.R., Weinhart, S. and Melzer, A. (2003) A combined system of lagoon and constructed wetland for an effective wastewater treatment. Water Research 37, 2035-2042.

Eckhardt, D.A.V. , Surface, J.m. and Peverly, J.H. 1999. A constructed wetland system for treatment of landfill leachate, Monroe County, New York. In Constructed Wetlands for the Treatment of Landfill Leachates CRC Press pp 205-222

Higgins, J. and Brown, T. 1999. The use of a constructed wetland to treat landfarm leachate at the Sunoco Refinery in Sarnia, Ontario. In Constructed Wetlands for the Treatment of Landfill Leachates CRC Press pp 235-249.

Appendix 1: SRC results of sample 1

Appendix 2: SRC results of sample 2

Appendix 3: Documents received from the city of Hamilton

Appendix3.xls Summary monitoring data

Blackport and Associates Hydrological Monitoring Review of the Upper Ottawa Street Landfill Site (November 2003)

University of Waterloo WRI Groundwater study 1984? Chapter 6 The direction of Flow of Groundwater

University of Waterloo WRI Groundwater study 1984? Chapter 7 The Chemical Content of Groundwater

Dames and Moore 1992 Monitoring Program at the Upper Ottawa St. Landfill Site (July 1993)

SNC-Lavalin 2003 Maps and Cross Section of Upper Ottawa St. Landfill Landfill Site

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Dec-19-2003

Boojum Research Limited
468 Queen St. E., Suite 400
Box 19
Toronto, Ontario M5A 1T7
Attn: Margarete Kalin

Date Samples Received: Dec-15-2003 Client P.O.:

SAMPLE	CLIENT DESCRIPTION
27980	12/12/2003 OLFL STAGNANT ASSAY # 10473 *WATER*
27981	12/12/2003 OLFL AIRED ASSAY # 10474 *WATER*
27982	12/12/2003 OLFL CIRCULATED ASSAY # 10475 *WATER*

ANALYTE	UNITS	27980	27981	27982
INORGANIC CHEMISTRY				
Bicarbonate	mg/L	1910	1460	1540
Carbonate	mg/L	113	169	82
Chloride	mg/L	840	775	965
Hydroxide	mg/L	<1	<1	<1
Sulfate	mg/L	130	130	170
Total alkalinity	mg/L	1750	1480	1400
Ammonia as nitrogen	mg/L	98	37	0.54
Nitrite+Nitrate nitrogen	mg/L	9.4	1.9	92
Total Kjeldahl nitrogen	mg/L	93	38	10
Biochemical oxygen demand	mg/L	43	37	1
Inorganic carbon	mg/L	398	321	319
Organic carbon	mg/L	90	57	124
Aluminum	mg/L	0.055	<0.005	<0.005
Barium	mg/L	0.037	0.015	0.076
Beryllium	mg/L	<0.001	<0.001	<0.001
Boron	mg/L	11.2	11.3	13.7
Cadmium	mg/L	<0.001	<0.001	<0.001
Chromium	mg/L	0.021	0.020	0.023
Cobalt	mg/L	0.010	0.008	0.021
Copper	mg/L	0.035	0.025	0.082
Iron	mg/L	0.26	0.13	0.090
Lead	mg/L	<0.002	<0.002	<0.002
Manganese	mg/L	0.021	0.007	0.089
Molybdenum	mg/L	0.010	0.008	0.013
Nickel	mg/L	0.059	0.044	0.059
Phosphorus	mg/L	0.39	0.29	1.1
Silicon, soluble	mg/L	15.3	15.2	17.2
Silver	mg/L	<0.001	<0.001	<0.001
Strontium	mg/L	1.38	0.99	1.8
Sulfur	mg/L	44	44	73
Titanium	mg/L	0.005	0.005	0.002
Vanadium	mg/L	0.010	0.010	0.012

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Dec-19-2003

SAMPLE	CLIENT DESCRIPTION
27980	12/12/2003 OLFL STAGNANT ASSAY # 10473 *WATER*
27981	12/12/2003 OLFL AIRED ASSAY # 10474 *WATER*
27982	12/12/2003 OLFL CIRCULATED ASSAY # 10475 *WATER*

ANALYTE	UNITS	27980	27981	27982
Zinc	mg/L	0.023	0.018	0.40
Zirconium	mg/L	0.011	0.010	0.008

"<": not detected at level stated above

4 day BOD analysis

All Analysis performed on unpreserved samples as per client.

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Boojum Research Limited
468 Queen St. E., Suite 400
Box 19
Toronto, Ontario M5A 1T7
Attn: Farhat

Jan-23-2004

Date Samples Received: Jan-05-2004 Client P.O.: BR001036

SAMPLE	CLIENT DESCRIPTION
151	12/23/2004 UOFL AIRED A 10491 *WATER*
152	12/23/2004 UOFL CIRCULATED A 10492 *WATER*
153	12/29/2004 UOFL CIRCULATED+OL D ROCKS A 10493 *WATER*

ANALYTE	UNITS	151	152	153
INORGANIC CHEMISTRY				
Chloride	mg/L	882	1340	920
Potassium	mg/L	250	330	260
Ammonia as nitrogen	mg/L	0.40	0.18	0.15
Nitrite+Nitrate nitrogen	mg/L	103	32	112
Total Kjeldahl nitrogen	mg/L	7.6	13	12
Biochemical oxygen demand	mg/L	3	6	2
Chemical oxygen demand	mg/L	320	464	280
Inorganic carbon	mg/L	256	290	181
Organic carbon	mg/L	150	140	58
Aluminum	mg/L	<0.005	<0.005	<0.005
Barium	mg/L	0.020	0.049	0.024
Beryllium	mg/L	<0.001	<0.001	<0.001
Boron	mg/L	12.6	15.7	13.0
Cadmium	mg/L	<0.001	<0.001	<0.001
Chromium	mg/L	0.021	0.021	0.020
Cobalt	mg/L	0.011	0.023	0.011
Copper	mg/L	0.027	0.068	0.038
Iron	mg/L	0.029	0.030	0.014
Lead	mg/L	<0.002	<0.002	<0.002
Manganese	mg/L	0.002	0.022	0.004
Molybdenum	mg/L	0.012	0.013	0.009
Nickel	mg/L	0.053	0.064	0.054
Phosphorus	mg/L	0.19	0.76	0.42
Silicon, soluble	mg/L	16.8	15.4	15.5
Silver	mg/L	0.001	<0.001	<0.001
Strontium	mg/L	0.92	1.24	0.80
Sulfur	mg/L	60	83	55
Titanium	mg/L	0.001	<0.001	<0.001
Vanadium	mg/L	0.010	0.014	0.012
Zinc	mg/L	0.021	0.22	0.10
Zirconium	mg/L	0.009	0.007	0.004

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Boojum Research Limited Jan-23-2004

Note for Sample # 151
* 4 day BOD.

SAMPLE		CLIENT DESCRIPTION
154	12/23/2004	UOFL BEGIN B 10494 *WATER*
155	12/24/2004	UOFL AIRED B 10495 *WATER*
156	12/24/2004	UOFL AIRED W ROCKS B 10496 *WATER*

ANALYTE	UNITS	154	155	156
INORGANIC CHEMISTRY				
Chloride	mg/L	755	254	410
Potassium	mg/L	200	230	220
Ammonia as nitrogen	mg/L	134	147	146
Nitrite+Nitrate nitrogen	mg/L	9.3	9.4	10
Total Kjeldahl nitrogen	mg/L	173	166	178
Biochemical oxygen demand	mg/L	187	58	151
Chemical oxygen demand	mg/L	332	280	332
Inorganic carbon	mg/L	273	290	275
Organic carbon	mg/L	98	78	65
Aluminum	mg/L	<0.005	<0.005	<0.005
Barium	mg/L	0.031	0.029	0.089
Beryllium	mg/L	<0.001	<0.001	<0.001
Boron	mg/L	10.8	11.4	11.1
Cadmium	mg/L	<0.001	<0.001	<0.001
Chromium	mg/L	0.024	0.021	0.021
Cobalt	mg/L	0.007	0.008	0.009
Copper	mg/L	0.017	0.021	0.033
Iron	mg/L	0.20	0.13	0.16
Lead	mg/L	<0.002	<0.002	<0.002
Manganese	mg/L	0.008	0.003	0.11
Molybdenum	mg/L	0.008	0.004	0.003
Nickel	mg/L	0.041	0.043	0.043
Phosphorus	mg/L	0.39	0.40	0.72
Silicon, soluble	mg/L	14.1	13.3	12.5
Silver	mg/L	0.001	0.001	0.001
Strontium	mg/L	1.23	1.11	0.90
Sulfur	mg/L	30	32	32
Titanium	mg/L	0.006	0.006	0.005
Vanadium	mg/L	0.009	0.010	0.009
Zinc	mg/L	0.019	0.017	0.19
Zirconium	mg/L	0.007	0.006	0.006

Note for Sample # 154
* 4 day BOD.

Note for Sample # 155

SRC Group: 2004-17

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Jan-23-2004

* 4 day BOD.

Note for Sample # 156

* 4 day BOD.

SAMPLE	CLIENT DESCRIPTION
157	12/24/2004 UOFL CIRCULATED B 10497 *WATER*
158	12/27/2004 UOFL CONTROL B 10498 *WATER*
159	12/27/2004 UOFL AIRED B 10499 *WATER*

ANALYTE	UNITS	157	158	159
INORGANIC CHEMISTRY				
Chloride	mg/L	412	407	760
Potassium	mg/L	220	210	230
Ammonia as nitrogen	mg/L	159	147	118
Nitrite+Nitrate nitrogen	mg/L	6.1	8.4	13
Total Kjeldahl nitrogen	mg/L	173	166	144
Biochemical oxygen demand	mg/L	228	106	39
Chemical oxygen demand	mg/L	308	280	296
Inorganic carbon	mg/L	370	279	201
Organic carbon	mg/L	130	79	54
Aluminum	mg/L	<0.005	<0.005	<0.005
Barium	mg/L	0.14	0.052	0.012
Beryllium	mg/L	<0.001	<0.001	<0.001
Boron	mg/L	11.6	8.4	11.8
Cadmium	mg/L	<0.001	<0.001	<0.001
Chromium	mg/L	0.023	0.015	0.022
Cobalt	mg/L	0.011	0.006	0.009
Copper	mg/L	0.027	0.012	0.021
Iron	mg/L	0.24	0.12	0.088
Lead	mg/L	<0.002	<0.002	<0.002
Manganese	mg/L	0.27	0.023	<0.001
Molybdenum	mg/L	0.003	0.005	0.005
Nickel	mg/L	0.044	0.030	0.044
Phosphorus	mg/L	1.1	0.31	0.38
Silicon, soluble	mg/L	14.6	10.1	14.2
Silver	mg/L	0.001	0.002	0.001
Strontium	mg/L	1.90	1.15	0.81
Sulfur	mg/L	34	23	34
Titanium	mg/L	0.005	0.004	0.005
Vanadium	mg/L	0.009	0.006	0.011
Zinc	mg/L	0.34	0.011	0.011
Zirconium	mg/L	0.007	0.007	0.006

Note for Sample # 157

* 4 day BOD.

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Note for Sample # 158
* 4 day BOD.

Note for Sample # 159
* 4 day BOD.

SAMPLE	CLIENT DESCRIPTION
160	12/27/2004 UOFL AIRED W ROCKS B 10500 *WATER*
161	12/27/2004 UOFL CIRCULATED B 10501 *WATER*
162	12/29/2004 UOFL CONTROL B 10502 *WATER*

ANALYTE	UNITS	160	161	162
INORGANIC CHEMISTRY				
Chloride	mg/L	620	780	499
Potassium	mg/L	180	210	250
Ammonia as nitrogen	mg/L	90	127	155
Nitrite+Nitrate nitrogen	mg/L	44	0.06	8.2
Total Kjeldahl nitrogen	mg/L	105	126	150
Biochemical oxygen demand	mg/L	132	66	77
Chemical oxygen demand	mg/L	332	280	296
Inorganic carbon	mg/L	169	460	348
Organic carbon	mg/L	28	56	88
Aluminum	mg/L	<0.005	<0.005	<0.005
Barium	mg/L	0.050	0.10	0.057
Beryllium	mg/L	<0.001	<0.001	<0.001
Boron	mg/L	8.3	11.6	12.5
Cadmium	mg/L	<0.001	<0.001	<0.001
Chromium	mg/L	0.015	0.021	0.024
Cobalt	mg/L	0.008	0.016	0.009
Copper	mg/L	0.026	0.018	0.023
Iron	mg/L	0.074	0.14	0.19
Lead	mg/L	<0.002	<0.002	<0.002
Manganese	mg/L	0.045	0.25	0.019
Molybdenum	mg/L	0.002	0.004	0.004
Nickel	mg/L	0.030	0.046	0.050
Phosphorus	mg/L	0.81	1.2	0.43
Silicon, soluble	mg/L	12.4	15.0	16.0
Silver	mg/L	<0.001	0.001	<0.001
Strontium	mg/L	0.94	1.81	1.60
Sulfur	mg/L	23	35	36
Titanium	mg/L	0.002	0.004	0.006
Vanadium	mg/L	0.006	0.008	0.010
Zinc	mg/L	0.15	0.31	0.020
Zirconium	mg/L	0.004	0.008	0.007

Note for Sample # 160

SRC Group: 2004-17

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Jan-23-2004

* 4 day BOD.

Note for Sample # 161

* 4 day BOD.

Note for Sample # 162

* 4 day BOD.

SAMPLE	CLIENT DESCRIPTION
163	12/29/2004 UOFL AIRED B 10503 *WATER*
164	12/29/2004 UOFL AIRED W ROCKS B 10504 *WATER*
165	12/29/2004 UOFL CIRCULATED B 10505 *WATER*

ANALYTE	UNITS	163	164	165
INORGANIC CHEMISTRY				
Chloride	mg/L	752	415	280
Potassium	mg/L	230	230	250
Ammonia as nitrogen	mg/L	78	12	24
Nitrite+Nitrate nitrogen	mg/L	27	140	91
Total Kjeldahl nitrogen	mg/L	89	90	30
Biochemical oxygen demand	mg/L	49	12	16
Chemical oxygen demand	mg/L	320	436	384
Inorganic carbon	mg/L	312	204	217
Organic carbon	mg/L	100	58	41
Aluminum	mg/L	<0.005	<0.005	<0.005
Barium	mg/L	0.013	0.063	0.096
Beryllium	mg/L	<0.001	<0.001	<0.001
Boron	mg/L	12.5	11.9	13.3
Cadmium	mg/L	<0.001	<0.001	<0.001
Chromium	mg/L	0.023	0.021	0.022
Cobalt	mg/L	0.009	0.016	0.020
Copper	mg/L	0.024	0.039	0.062
Iron	mg/L	0.098	0.094	0.075
Lead	mg/L	<0.002	<0.002	<0.002
Manganese	mg/L	0.001	0.12	0.21
Molybdenum	mg/L	0.005	0.005	0.006
Nickel	mg/L	0.049	0.046	0.052
Phosphorus	mg/L	0.41	1.0	0.65
Silicon, soluble	mg/L	16.0	13.9	14.9
Silver	mg/L	0.002	<0.001	<0.001
Strontium	mg/L	0.87	1.33	1.91
Sulfur	mg/L	36	35	40
Titanium	mg/L	0.004	0.002	0.002
Vanadium	mg/L	0.011	0.009	0.011
Zinc	mg/L	0.016	0.31	0.27
Zirconium	mg/L	0.005	0.004	0.005

SRC Group: 2004-17

SRC ANALYTICAL

Boojum Research Limited Jan-23-2004

Note for Sample # 163
* 4 day BOD.

Note for Sample # 164
* 4 day BOD.

Note for Sample # 165
* 4 day BOD.

SAMPLE CLIENT DESCRIPTION
166 12/29/2004 UOFL AIRED + NEW ROCKS A 10506 *WATER*

ANALYTE	UNITS	166
INORGANIC CHEMISTRY		
Chloride	mg/L	1320
Potassium	mg/L	310
Ammonia as nitrogen	mg/L	0.03
Nitrite+Nitrate nitrogen	mg/L	33
Total Kjeldahl nitrogen	mg/L	20
Biochemical oxygen demand	mg/L	4
Chemical oxygen demand	mg/L	412
Inorganic carbon	mg/L	291
Organic carbon	mg/L	110
Aluminum	mg/L	<0.005
Barium	mg/L	0.045
Beryllium	mg/L	<0.001
Boron	mg/L	17.7
Cadmium	mg/L	<0.001
Chromium	mg/L	0.024
Cobalt	mg/L	0.029
Copper	mg/L	0.088
Iron	mg/L	0.027
Lead	mg/L	<0.002
Manganese	mg/L	0.014
Molybdenum	mg/L	0.015
Nickel	mg/L	0.079
Phosphorus	mg/L	1.4
Silicon, soluble	mg/L	16.2
Silver	mg/L	0.001
Strontium	mg/L	1.27
Sulfur	mg/L	97
Titanium	mg/L	<0.001
Vanadium	mg/L	0.018
Zinc	mg/L	0.22
Zirconium	mg/L	0.004

SRC Group: 2004-17

SRC ANALYTICAL

Boojum Research Limited Jan-23-2004

"<": not detected at level stated above

Note revised BOD results.

Appendix 3: Manhole Leachate of Upper Ottawa Landfill Site

Analyte	Sewer Discharge Criteria	Provincial Water Quality Objectives	2003-10-06	2003-04-23	2002-12-16	2002-11-21	2002-06-21	2001-06-08	2000-09-15	2000-05-30	1999-08-06
Alkalinity mg/L			2980	1860		947	2760	2380	2680	2670	3360
Ammonia as N mg/L			228	103		4.42	207	188	199	202	313
Bicarbonate as Carbonate mg/L			2980	1860		947	2760	2380	2680	2670	3360
Carbonate mg/L			<3	<1		<1	<1	<1	<1	<1	<0.5
cBiochemical Oxygen Demand mg/L	=300		73	23	34	**18**	<55	38	45	38	**77**
Chemical Oxygen Demand mg/L			776	309		**295**	340	601	694	524	**996**
Chloride mg/L	=1500		1200	485	1090	215	906	862	1020	904	1300
Conductivity umhos/cm			8350	4740		2440	7260	6840	7200	4160	983
Cyanide - Total mg/L	=2	0.005	0.028	0.013	0.017	0.011	0.017	0.014	0.028	0.025	0.03
Dissolved Organic Carbon mg/L			180	90.1		**18.3**	132	141	157	150	**195**
Fluroide mg/L	=10		2.32	1.89		0.4	2.46	2.22	2.17	2.23	3.43
Hardness mg/L			882	990		1930	968	946	861	949	873
Hydroxide ion as Carbonate mg/L			<3	<1		<1					
Nitrate as N mg/L			3.2	5.58		16.2	20.7				
Nitrate + Nitrite as N mg/L			3.57	6.02		16.3		0.64	0.68	1.53	0.73
Nitrite as N mg/L			0.37	0.44		0.08	2.13				
pH pH	5.5-9.5	6.5-8.5	7.99	7.96	8.01	7.82	8.07	7.79	7.78	7.58	7.81
pH - saturation			6.34	6.25		5.98	6.23	6.21	6.3	6.23	6.33
Phenols mg/L	=1	0.001	0.15	0.009	0.014	<0.003	0.009	0.008	0.01	0.011	0.018
Phosphorus Total mg/L	=10	0.01	1.85	0.536	0.959	3.5	1	0.798	1.01	1.03	1.7
Silica - Reactive mg/L			36.1	29		42.1	37.8	18.1	38.4	35.2	36.7
Sulphate mg/L	=1500		43.1	135	104	81.3	28.8	55.5	55	75	<100
Temperature C			22.6	20.1		22.4	23.2	23.2	22.4	21.4	22.1
Total Dissolved Solids mg/L			4880	2810		1540	4160	3830	4280	4080	5530
Total Kjeldahl Nitrogen as N mg/L	=100		273	120	177	15.5	252	216	209	202	314
Total Suspended Solids mg/L	=350		68	5.5	9	1880	2.8	5.8	40	8.6	<1.5
Turbidity NTU			13.4	4.25		1360	8.76	11.8	6.26	8.23	5.09
Oil & Grease - Vegetable	150				7						
Oil & Grease - Mineral	15				<4						

Analyte											
Ammonia (un-ionized) ug/L				1720		134					

Analyte											
Anion Sum me/L			84.7	47.9		24.7	72.6	65.1	75	71.9	92.9
Cation Sum me/L			85.1	52		59	73.6	66.7	70	66.8	95.5
Ion Balance %			0.24	4.1		41	0.68	1.21	3.45	-3.68	1.38

Analyte											
Antimony mg/L	=5	0.02	<0.0006	0.001	<0.001	<0.01	<0.001	<0.001	<0.001	<0.001	0.001
Arsenic mg/L	=1	0.005	0.002	0.001	0.002	0.018	0.002	0.002	0.001	0.002	0.003
Barium mg/L			0.477	0.266	0.488	0.446	0.419	0.381	0.426	0.385	0.533
Beryllium mg/L		0.011	<0.0001	<0.0001	<0.0001	0.0031	<0.0001	<0.0001	0.0001	0.0014	0.0032
Bismuth mg/L	=5		<0.1	<0.10	<0.1	<0.01	<0.10	<0.1	<0.10	<0.1	0.19
Boron mg/L		0.2	16.4	8.06		1.89	14.4				
Cadmium mg/L	=1	0.0002	0.0003	0.0001	<0.001	0.0004	0.0003	<0.001	0.0011	<0.0006	<0.0006
Calcium mg/L			79.5	144		474	104	120	94.2	113	75.8
Chromium mg/L	=5		0.05	0.021	0.042	0.226	0.041	0.03	0.038	0.039	0.06
Cobalt mg/L	=5	0.0009	0.015	0.0078	0.0144	0.0358	0.0107	0.014	0.0143	0.012	0.0212
Copper mg/L	=3	0.005	0.02	0.025	0.03	0.206	0.019	0.007	0.012	0.014	0.025
Dissolved Aluminum mg/L	=50		<0.05	0.06	0.14	<0.05	<0.05	<0.05	<0.05	<0.05	
Iron mg/L	=50	0.3	2.65	1.3	1.89	82.5	2.76	2.74	2.02	2.44	2.88
Lead mg/L	=5	0.003	0.003	0.003	<0.02	0.3	0.002	0.004	<0..005	<0.005	0.04
Magnesium mg/L			166	153		181	172	157	152	162	166
Manganese mg/L	=5		0.248	0.369	0.248	3.44	0.368	0.497	0.393	0.607	0.344
Mercury-Dissolved ug/L	=0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.4	<0.4
Molybdenum mg/L	=5	0.04	<0.01	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.02
Nickel mg/L	=3	0.025	0.0733	0.039	0.069	0.093	0.061	0.059	0.075	0.08	0.111
Potassium mg/L			293	142		135	236	221	237	216	353
Selenium mg/L	=5	0.1	<0.002	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.003	<0.002
Silver mg/L	=5	0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002
Sodium mg/L			1270	603		267	1010	962	1070	966	1580
Strontium mg/L			2.25	2.41	3.35	3.55	2.43	3.06	3.13	2.82	4.3
Thallium mg/L		0.0003	<0.10	<0.10	<0.10	<0.10	<0.10	<0.1	<0.11	<0.11	<0.11
Tin mg/L	=5		0.02	<0.02	<0.02	0.02	<0.02	0.02	0.03	<0.01	<0.01
Titanium mg/L	=5		0.047	0.016	0.04	1.43	0.025	0.024	0.029	0.03	0.056
Vanadium mg/L	=5	0.006	0.026	0.01	0.011	0.123	0.008	0.017	<0.005	0.008	0.025
Zinc mg/L	=3	0.02	0.073	0.099	0.06	2	0.05	0.05	0.05	0.1	0.11

Analyte											
Temperature - Field C				10							